Diffusion determinants for passive building technologies

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This paper addresses the research question, ‘‘What are the diffusion determinants for passive building technologies in Australia?’. This is a significant topic given the global movement towards greener buildings. The study reported here is based on desktop research that provides new insights through (1) synthesis of the latest research findings on passive building technologies and (2) interpretation of diffusion issues through our innovation system model. Although innovation determinants have been studied extensively overseas and in Australia, there is presently a gap in the literature when it comes to these determinants for green buildings in Australia. The current paper fills this gap. Using a conceptual framework drawn from the innovation systems literature, this paper synthesises and interprets the literature to map the current state of passive building technologies in Australia and to analyse the drivers for, and obstacles to, their optimal diffusion.

The project-based nature of production in the construction sector creates unique challenges to the adoption of innovation, compared to say, the manufacturing sector, for example. The temporary nature of teams makes it difficult to build up the strength of relationships often needed for successful innovation. In addition, the project to project production method implies a discontinuity which makes the accumulation of knowledge within project based firms difficult. These factors were predicted in theory to play an important role in the adoption of passive building technologies. This was supported the content analysis undertaken for the current study, which was guided by an innovation system framework which emphasises the relationships between actors and activities within the Construction Product System.

The paper concludes that australian governments have an important role to play in facilitating improved adoption rates. This applies to governments in their various roles, but particularly as clients, regulators, and investors in education, training, research and development.

In their role as clients for government buildings, the report suggests that government can better facilitate innovation within the Construction Product System by reviewing their specification policies and adjusting them to encourage better use of passive building technologies on government projects. Specification of client requirements within tenders should be based on performance parameters, rather than on detailed prescription of methods and materials. Further, performance-based parameters need to be specified in very broad, high-level terms, to encourage the most innovative solutions possible. It is expected that if substantive policy changes are made in this respect, then over time significant improvements in project and built asset performance could be expected, in turn encouraging private sector clients to follow the government’s lead.

In their role as regulators, Australian governments face particular challenges associated with our federal system of government and associated duplication and uncertainty. This means that innovators often face high costs associated with approval processes. In relation to the BCA, recent reforms towards performance-based specifications have helped to encourage innovators, yet stakeholders would like to see performance specified at higher levels of aggregation, providing more flexibility in possible solutions. In relation to setting standards generally, the need for greater interoperability within our federal system and internationally is urgent. More rigorous and pervasive mandatory sustainability standards are required, as in many cases current standards are well below European and US requirements.

In relation to the government's role in 'education, training, research and development', stakeholder conservatism and lack of adequate understanding of the net benefits associated with passive building technologies over the long-term are hampering innovation adoption. These issues require increased government funding of training activities, education programs, and demonstration initiatives.

Future research will build on the results of this exploratory study through extensive fieldwork which is planned to quantify the barriers to the adoption of green building innovations in Australia.

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SUMMARY

This paper is based on an international review of leading peer reviewed journals, in both technical and management fields. It draws on highly cited articles published between 2000 and 2009 to investigate the research question, 'What are the diffusion determinants for passive building technologies in Australia?'. Using a conceptual framework drawn from the innovation systems literature, this paper synthesises and interprets the literature to map the current state of passive building technologies in Australia and to analyse the drivers for, and obstacles to, their optimal diffusion. The paper concludes that the government has a key role to play through its influence over the specification of building codes.

Keywords: innovation, passive building technologies, Australia

1. Introduction

Passive building technologies are an important part of energy saving in commercial and residential buildings, and as such are a key element in our response to climate change and the need for sustainable environmental development. Passive building technologies are part of the Green Building Movement which has gathered considerable momentum since the global community had its first significant meeting to consider global environmental needs and appropriate responses at the first United Nations Earth Summit in 1972 in Stockholm. This was followed with two more Earth Summits; Rio de Janeiro in 1987 and Johannesburg in 2002. The next Summit is scheduled for Rio De Janeiro in 2012. These events have driven global interest in environmental sustainability, along with key reports, such as the seminal Brundtland Report [1].

In the last few years, concern about environmental degradation and the drivers of required change have focused on a number of themes, including the weight of evidence provided by the increasing frequency and impact of disasters [2], the economic cost of required adjustment [3], the need for system-wide approaches to change [4], the symbiosis between the built environment and human experience [5]; the importance of socio-political change [6]; and the importance of technical change [7].

Although the role of technical change is by no means the most important of these issues, it is nevertheless a key element in the path to optimal environmental impacts. This paper focuses on a sub-sector of the technical change issue, first of all zeroing in on green buildings as a key element of the built environment, and within that focused on their energy usage and the nature of diffusion determinants for passive building technologies. Green buildings are those that result from 'a systematic effort to create, sustain, and accelerate changes in practice, technology and behaviour to reduce building-related environmental impacts while creating places that are healthier and more satisfying for people' [5]. Green buildings always incorporate passive technologies and these technologies typically reduce or eliminate the need for active systems to maintain thermal an optical comfort. A very recent study comprehensively reviews passive technologies on worldwide building projects and notes the importance of the following technologies in achieving net zero energy solar buildings [8] :

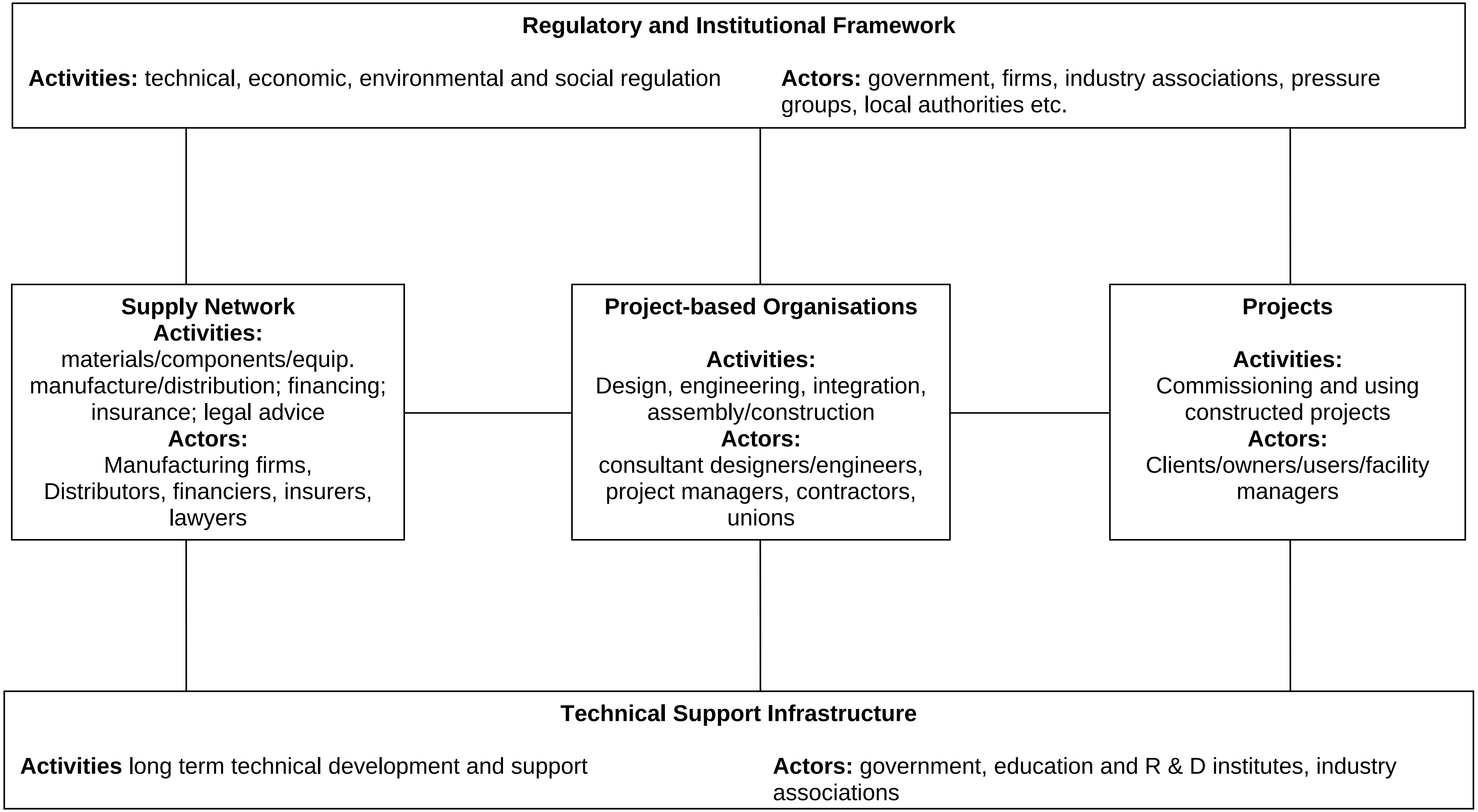
- Advanced termal insulation
- High thermal mass
- Advanced daylighting
- Advanced solar heat gains
- Sunshading
- Mechanical ventilation
- Heat recovery
- Passive cooling or ventilation
- Solar thermal DHW
- Solar-assisted space heating/DHW

This paper focuses on a subsector of these technologies; those that emerged as prominent in the Australian context. The point of our research however, is not to examine the technical details of the technologies, but to investigate the determinants of their adoption. We undertook a comprehensive literature review to pursue the research question, ‘‘What are the diffusion determinants for passive building technologies in Australia?’. This is a significant topic given the global movement towards greener buildings as described above. Although innovation determinants have been studied extensively overseas and in Australia [10], there is presently a gap in the literature when it comes to these determinants for green buildings in Australia. The current paper fills this gap.

2. Methods and Conceptual Background

This paper is based on a international review of leading peer reviewed journals, in both technical and management fields. It draws on highly cited articles published between 2000 and 2009. The articles dealt with the adoption of passive building technologies in Australia. Content analysis was employed to understand the adoption environment in view of the conceptual framework, which is shown in Figure 1. The authors each independently allocated the themes arising in the literature to the activities and actors shown in Figure 1. Following this, the two sets of analysis were merged and triangulated to arrive at a consensus understanding of the nature of key determinants. We employed an innovation system framework to understand adoption determinants. The framework is shown in Figure 1 and reveals the relationships between key activities and actors involved in the creation of the built environment. The regulatory and institutional framework shapes, and is shaped by, the supply network, project-based firms and projects themselves, with the technical support infrastructure playing a similar role.

Figure 1: Activities and Actors in the Construction Product System



Source: Based on: Gann and Salter 2000[9]

The framework in Figure 1 emphasises the relationships and interdependencies in the built environment product system. Indeed, the project-based nature of production in the construction sector creates unique challenges to the adoption of innovation, compared to say, the manufacturing sector, for example. The temporary nature of teams makes it difficult to build up the strength of relationships often needed for successful innovation. In addition, the project to project production method implies a discontinuity which makes the accumulation of knowledge within project based firms difficult [10]. These factors were predicted in theory to play an important role in the adoption of passive building technologies.

3. Passive Building Technologies – Physical Description

Passive eco-design is a key element of a sustainable building and incorporates advanced technologies that represent emerging design innovations in Australia. The principles underlying passive eco-design aim to maximise the thermal comfort levels of the building occupants while minimising energy use and the need for mechanical heating and cooling systems [11]. Passive design targets natural energy resources, such as solar energy, to provide cooling, heating, ventilation and lighting to building occupants. Passive design principles can be applied to both commercial and residential buildings and can be applied to a wide range of conditions.

As the design functions of a building are highly interdependent, it is important that designers take a holistic approach to the integration of passive eco-design technologies. Not only should the impact of integrating passive and active design technologies be considered, but an individualised approach should also be considered, taking into account the location of the proposed building, climate, orientation and expected occupant comfort levels. Further, as Australia has large climatic variations between regions and seasons, passive eco-design is required to be flexible to manage current climate fluctuations and future climate change predictions. Recommendations in this and related areas have been provided by three research projects funded by the CRC for Construction Innovation: ‘Energy efficient subdivisions’, ‘Water efficient subdivisions’ and ‘Subdivision design for ventilation’.

According to Ambrose [12], the basic principles of eco-efficient passive design are:

- *Orientation* – the design should provide for shading during summer and maximum solar gain during winter. This is a core principle of passive solar design and can significantly reduce the need for artificial heating and cooling. The ideal orientation for a building will depend on the climatic and regional conditions, but generally speaking, in hot humid or dry climates, orientation should aim to exclude sun all year round with design focusing on maximising exposure to cooling breezes. However, in cooler climates, a combination of passive cooling and solar heating is required. Such buildings are ideally constructed on a block running North – South to capture low elevation winter sun and the use of shading devices on the northern elevation to minimise high angle summer sun [13].

- *Layout and zoning* – the design should provide internal layouts that place common areas to the north and provide good natural lighting and ventilation.

- *Insulation* – the design should provide wall, ceiling and floor insulation to slow heat transfer.

- *Windows and shading* – the design of window size and placement should aim to maximise natural light and passive solar heat gain, using shading devices to shield windows from summer sun.

- *Ventilation and draft proofing* – the design should capture natural cooling breezes during summer and prevent the escape of cooling from air conditioning systems.

- *Thermal mass* – the design should use ‘thermally massive’ materials to store heat and discharge it at night.

- *Landscaping* – the landscape design should aim to maximise shading and capture breezes.

Recently, the emergence of advanced ‘passive design’ materials and products has increased the options available to designers when designing eco-efficient buildings. The advancements in building product technologies have led to improved design methods that take advantage of building positioning and protect occupants from the extremes of Australia’s varied climate zones. The following provides a cross-section of emerging building technologies that are improving the passive eco-efficiency of buildings with the potential for uptake in Australia.

3.1 Passive Solar Lighting Systems

A well-known approach to capturing natural light in a building is the use of skylights or solar tubes with reflective surfaces. A recent evolution of passive solar lighting and the traditional skylight is the development of ‘Hybrid solar lighting’ (HSL). HSL applies a novel approach in capturing sunlight, channelling it directly into a room using optical fibres. Currently targeting commercial buildings, this technology uses mirrored dish rooftop collectors that track the sun with the assistance of daylight harvesting sensors. The dish then focuses the collected sunlight onto 127 optical fibres, bundled into a single cord. This cord is then connected to special hybrid light fixtures that diffuse light in all directions. Currently, this technology has not evolved into a cost-effective lighting solution due to its technical complexity. However, with further development, it is expected that costs will fall by 50% over the next two years [14].

3.2 Advanced Insulation Technology

Transparent and dynamic insulation are two emerging insulation technologies that have the potential to improve the passive solar efficiency of a building. Firstly, Transparent Insulation Material (TIM) represents a new class of thermal insulation that consists of a transparent honeycomb array immersed in an air layer [15]. TIM is solar transparent, yet provides good thermal insulation and prevents large radiation losses that can occur with traditional glazing. The material can also be used as an external building insulation layer. Secondly, dynamic insulation aims to capture escaping radiant heat through a permeable insulation layer. External air is then drawn through the insulation layer that forms the building envelope, and is heated as it passes [16]. The system uses an ‘active’ external fan to draw out air so that the internal space becomes depressurised to allow external air to be drawn through the insulation. This requires strict air leakage control as the entire system depends on adequate depressurisation. Although dynamic insulation requires a powered ventilation system and the technology cost profile is still problematic, it offers the potential to minimise radiant heat loss without the use of thick traditional insulating materials.

3.3 Insulate and Spectrally-Selective Glazing

Special glazing systems with low emissive or spectrally sensitive (SS) coatings are being increasingly used on buildings and can contribute significantly to the passive solar efficiency of a building. This technology modulates the glazing’s optical properties, allowing shortwave energy (daylight) to pass while limiting the absorption and loss of infra-red radiation (heat) within the pane. This results in significantly reduced heat loss through the glass and can act as a mirror to long wave radiation of building interiors [17]. SS glass can be ideally integrated into double glazing technology to maximise the control of solar radiation. Double glazing technology comprises two panes of glass with a sealed space in between to increase insular properties. This space is generally filled with air or an inert gas and provides better thermal properties than a single pane.

3.4 Dynamic Facade and Shade Systems

Dynamic shade systems are a new innovative technology driven by the demand for transparent building façades and energy efficiency. They are used for the optimal control of solar energy. Generally, these systems include roller shades that move automatically to redirect sunlight and allow diffused light into a building space, while horizontal blinds automatically redirect natural light uniformly. These systems can be coupled with automated windows to allow for natural ventilation at certain times. They can also be linked with the simultaneous control of electric lighting, ventilation and air conditioning and can reduce energy consumption for lighting and cooling, while maintaining optimal thermal and lighting indoor conditions [18]. Each of these systems needs to be tailored to a specific climate, location and orientation.

3.5 Passive Eco-Efficiency Modelling

Modern computer modelling technology has improved the optimisation of the passive building design process. This technology allows designers to model the thermodynamics and heat transfer properties of building materials, analyse climatic conditions (matching building design with specific climate variations and solar orientation), and predict solar gain potential. Such emerging technologies are assisting designers to achieve significant building energy savings, while retaining functionality, thermal comfort and aesthetics. Secondly, designers can potentially evaluate design elements and passive energy efficiency prior to the commencement of construction on-site. Passive eco-efficiency is a key construction management dimension that can be incorporated into digital building models [7].

4. Passive Building Technologies – System Dynamics

The benefits of passive design principles coupled with advancements in passive solar technology and building products offer benefits to clients and owners in the improved long-term energy efficiency of their buildings. Referring back to the conceptual framework shown in Figure 1, the literature review above indicates that in Australia passive building technologies are driven by: 1) environmental and technical regulations (such as minimum energy performance standards and Building Council of Australia requirements); 2) from material, component and equipment manufacturing (through advanced passive eco-efficient products such as those discussed above), and importantly; 3) through design, engineering, integration and construction. Without the interest and relevant knowledge base of project-based actors such as consultant designers, optimal eco-efficient design solutions will not be fully realised.

Support infrastructure actors (such as industry associations and government bodies) are taking a leadership position in advocating the benefits that can be achieved through passive eco-design technologies. Awareness and education campaigns targeted at design and engineering professionals have been developed and implemented, with the Australian Institute of Architects ‘continuing education program’ [19], and the Australian Government’s *YourHome* initiative [20] being examples. Similarly, with the development of emerging eco-profiling and modelling technologies by R&D institutes, designers and engineers have greater confidence in the efficiency of their proposed design solutions. Such systems also have an impact on end-product actors (owners, users and facility managers) as they provide the tools for the ongoing monitoring of passive energy systems (e.g. building thermal efficiency).

Passive building design focusing on energy efficiency is not a new concept. Indeed, its principles have been applied for centuries in traditional building design, and in Australia, originated from the need for residential buildings to minimise the harsh climatic variations, without the option of mechanical heating and cooling systems available today. An early example of passive eco-design is elevated and high ventilation homes in hot and humid climates which take advantage of the natural cooling breezes.

The benefits of passive eco-efficient building design are being increasingly recognised by the Australian construction industry andG. An example of this is the Australian Government's recent inclusion of mandatory requirements for residential buildings to meet energy efficiency performance standards. These standards have been facilitated nationally through inclusions to the Building Code of Australia (BCA) and supplemented through individual state government regulations. Regulations specifying commercial buildings' energy efficiency requirements have been slower to appear than for residential buildings, but are now part of the current regulations [11].

Although these regulations focus on active systems (such as solar hot water, energy and lighting; and appliance requirements), passive design systems have been acknowledged in the regulations as an important component to an eco-efficient design solution which can significantly influence the overall operating energy efficiency of a building. Indeed, the BCA 5-star regulations require the rating of the 'thermal efficiency' of a building envelope. Yet, there is still much to be done in this area. For example, the current thermal requirements in the BCA for Australian dwellings are still well below European and US building requirements. The comparatively low rating requirements in Australia are reflected in higher per capita domestic energy consumption in Australia [12].

Passive design has primarily been applied to the residential building sector in the past, with increasing interest in and from the commercial sector. Recent examples of commercial buildings that incorporate passive design principles have emerged. One such example is the *CH2* building in Melbourne that uses integrated passive and active systems to control the indoor office environment, and is regarded as Australia's 'greenest' office building [11]. The building utilises natural ventilation and thermal mass technology whereby the concrete ceiling slab absorbs excess heat during the day and releases it at night. It also utilises an underfloor convective heating system that forces warm air (captured partly from excess heat from a co-generation plant) through the office areas during the cooler months in Melbourne.

4.1 Diffusion Issues

There remain significant opportunities for the uptake of advanced eco-efficient design in Australia. Although new technology and products are emerging that support the development of passive energy-efficient building design, uptake is not at optimal levels. Of note, in the housing industry, sustainable housing technology is being successfully developed; however, its uptake is being significantly hampered by issues of awareness and communication in Australia [21]. As such, the supply network and regulatory bodies (including government) should be focusing on packaging environmental products that are cost-competitive with minimum trade-off in functionality; and disseminating the full benefits of passive eco-efficient design (integrated with eco-efficient *active* systems such as heating, ventilation and air conditioning). Also, increased specification by clients of environmental performance requirements in project briefs (including passive design requirements) will be of benefit to project outcomes. This will provide the information to the designers on what environmental performance levels are required to be met and prevent costly changes during design development [22].

Other obstacles include a lack of incentives through regulation which perhaps could be made tougher, including the comparatively low building rating requirements for thermal efficiency in Australia, compared to other western countries [12]. Raising performance standards will have downstream effects for clients to further consider passive design performance in areas such as natural ventilation and solar access.

Despite the obvious benefits of eco-efficient building design, there are potential downsides to early adoption. These include potentially higher upfront costs to clients and the risks associated with sub-optimal design performance once the building is constructed. In some cases, eco-efficient design will also require clients to compromise comfort, functionality and ease-of-use to enhance ecological sustainability.

5. Conclusions

Australia has three key assets – its people, its built environment and its natural environment. This report concerns itself with the role that people play in generating innovation to improve the value for money provided by the built environment, while preserving and enhancing the natural environment. Passive building technologies offer significant performance improvement across the Construction Product System in Australia. These innovations contribute in a significant way to creating a more sustainable built environment in Australia.

Overwhelming, this paper points to the important role played by Australian governments in facilitating improved adoption rates. This applies to governments in their various roles, but particularly as clients, regulators, and investors in education, training, research and development.

In their role as clients for government buildings, the report suggests that government can better facilitate innovation within the Construction Product System by reviewing their specification policies and adjusting them to encourage better use of passive building technologies on government projects. Specification of client requirements within tenders should be based on performance parameters, rather than on detailed prescription of methods and materials. Further, performance-based parameters need to be specified in very broad, high-level terms, to encourage the most innovative solutions possible. It is expected that if substantive policy changes are made in this respect, then over time significant improvements in project and built asset performance could be expected, in turn encouraging private sector clients to follow the government's lead.

In their role as regulators, Australian governments face particular challenges associated with our federal system of government and associated duplication and uncertainty. This means that innovators often face high costs associated with approval processes. In relation to the BCA, recent reforms towards performance-based specifications have helped to encourage innovators, yet stakeholders would like to see performance specified at higher levels of aggregation, providing more flexibility in possible solutions. In relation to setting standards generally, the need for greater interoperability within our federal system and internationally is urgent. More rigorous and pervasive mandatory sustainability standards are required, as in many cases current standards are well below European and US requirements.

In relation to the government's role in 'education, training, research and development', stakeholder conservatism and lack of adequate understanding of the net benefits associated with passive building technologies over the long-term are hampering innovation adoption. These issues require increased government funding of training activities, education programs, and demonstration initiatives.

The study reported here is based on desktop research that provides new insights through (1) synthesis of the latest research findings on passive building technologies and (2) interpretation of diffusion issues through our innovation system model. Future research will build on the results of this exploratory study through extensive fieldwork which is planned to quantify the barriers to the adoption of green building innovations in Australia.

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